Stellar masses, star formation rates, metallicities and AGN properties for 2×10^5 galaxies in the SDSS Data Release Two (DR2)

Jarle Brinchmann[1,2], Stéphane Charlot[1,3], Timothy M. Heckman[4], Guinevere Kauffmann [1], Christy Tremonti[5,4], Simon D.M. White[1]

Abstract

By providing homogeneous photometric and spectroscopic data of high quality for very large and objectively selected samples of galaxies, the Sloan Digital Sky Survey allows statistical studies of the physical properties of galaxies and AGN to be carried out at an unprecedented level of precision and detail. Here we publicly release catalogues of derived physical properties for 211,894 galaxies, including 33,589 narrow-line AGN. These are complete samples with well understood selection criteria drawn from the normal galaxy spectroscopic sample in the second SDSS public data release (DR2). We list properties obtained from the SDSS spectroscopy and photometry using modelling techniques presented in papers already published by our group. These properties include: stellar masses; stellar mass-to-light ratios; attenuation of the starlight by dust; indicators of recent major starbursts; current total and specific star-formation rates, both for the regions with spectroscopy and for the galaxies as a whole; gas-phase metallicities; AGN classifications based on the standard emission line ratio diagnostic diagrams and AGN [OIII] emission line luminosities. We also list our own measurements of absorption line indices and emission line fluxes from which these quantities were derived, together with a few quantities from the standard SDSS pipelines which play an important role in our work. Many other observed properties of these galaxies can be obtained from the SDSS DR2 catalogues themselves. We will add further physical properties to this release site as the relevant papers are accepted for publication. Catalogues containing these parameters may be accessed at http://www.mpa-garching.mpg.de/SDSS/.

[1] *Max-Planck Institut für Astrophysik, D-85748 Garching, Germany*
[2] *Centro de Astrofísica da Universidade do Porto, Rua das Estrelas - 4150-762 Porto, Portugal*
[3] *Institut d'Astrophysique du CNRS, 98 bis Boulevard Arago, F-75014 Paris, France*
[4] *Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218*
[5] *Steward Observatory, 933 N. Cherry Ave., Tucson, AZ 85721, USA*

1 The SDSS Data

The galaxy spectra we have analyzed are drawn from the Sloan Digital Sky Survey (SDSS). The survey goals are to obtain photometry of a quarter of the sky and spectra of nearly one million objects. Imaging is obtained in the *u, g, r, i, z* bands (Fukugita et al 1996; Smith et al 2002) with a special purpose drift scan camera (Gunn et al 1998) mounted on the SDSS 2.5 meter telescope at Apache Point Observatory. The imaging data are photometrically (Hogg et al 2001) and astrometrically (Pier et al 2003) calibrated, and used to select stars, galaxies, and quasars for follow-up fiber spectroscopy. Spectroscopic fibers are assigned to objects on the sky using an efficient tiling algorithm designed to optimize completeness (Blanton et al 2003). The details of the survey strategy can be found in (York et al 2000) and an overview of the data pipelines and products is provided in the Early Data Release paper (Stoughton et al 2002).

Our sample for this study is composed of 211,894 objects which have been spectroscopically confirmed as galaxies and have data publicly available in the SDSS Data Release 2 (Abazajian et al 2004). These galaxies are part of the SDSS 'main' galaxy sample used for large scale structure studies (Strauss et al 2002) and have Petrosian r magnitudes in the range $14.5 < r < 17.77$ after correction for foreground galactic extinction using the reddening maps of Schlegel,Finkbeiner & Davis (1998). Their redshift distribution extends from ~ 0.005 to 0.30, with a median z of 0.10.

The spectra are obtained with two 320-fiber spectrographs mounted on the SDSS 2.5-meter telescope. Fibers 3 arcseconds in diameter are manually plugged into custom-drilled aluminum plates mounted at the focal plane of the telescope. The spectra are exposed for 45 minutes or until a fiducial signal-to-noise (S/N) is reached. The median S/N per pixel for galaxies in the main sample is ~ 14. The spectra are processed by an automated pipeline (Schlegel et al., in prep.) which flux and wavelength calibrates the data from 3800 to 9200 Å. The instrumental resolution is R $\equiv \lambda/\delta\lambda = 1850 - 2200$ (FWHM$\sim$ 2.4 Å at 5000 Å).

The Survey has been able to obtain a remarkable level of spectrophotometric precision by the simple practice of observing multiple standard stars simultaneously with the science targets. (The artifice in this case is that the 'standards' are not classical spectrophotometric standards, but are halo F-subdwarfs that are calibrated to stellar models – see Abazajian et al (2004) for details.) To quantify the quality of the spectrophotometry we have compared magnitudes synthesized from the spectra with SDSS photometry obtained with an aperture matched to the fiber size. The 1σ error in the synthetic colors is 5% in $g - r$ and 3% in $r - i$ ($\lambda_g \sim 4700$ Å; $\lambda_r \sim 6200$ Å; $\lambda_i \sim 7500$ Å). At the bluest wavelengths (~ 3800 Å) we estimate the error to be $\sim 12\%$ based on repeat observations.

2 Emission Line Measurements

The optical spectra of galaxies are very rich in stellar *absorption* features, which can complicate the measurement of nebular emission lines. In order to maintain speed and flexibility, the SDSS spectroscopic pipeline performs a very simple estimate of the stellar continuum using a sliding median. While this is generally adequate for strong emission lines, a more sophisticated

treatment of the continuum is required to recover weak features and to properly account for the stellar Balmer absorption which can reach equivalent widths of 5 Å in some galaxies. To address this need, we have designed a special-purpose code optimized for use with SDSS galaxy spectra which fits a stellar population model to the continuum. We adopt the basic assumption that any galaxy star formation history can be approximated as a sum of discrete bursts. Our library of template spectra is composed of single stellar population models generated using the new population synthesis code of Bruzual & Charlot (2003; BC03). The BC03 models incorporate an empirical spectral library (Le Borgne et al 2003; in preparation) with a wavelength coverage (3200 - 9300 Å) and spectral resolution ($\sim$ 3 Å) which is well matched to that of the SDSS data. Our templates include models of ten different ages (0.005, 0.025, 0.1, 0.2, 0.6, 0.9, 1.4, 2.5, 5, 10 Gyr) and three metallicities (1/5 $Z_\odot$, $Z_\odot$, and 2.5 $Z_\odot$). For each galaxy we transform the templates to the appropriate redshift and velocity dispersion and resample them to match the data. To construct the best fitting model we perform a non-negative least squares fit with dust attenuation modeled as an additional free parameter. In practice, our ability to simultaneously recover ages and metallicities is strongly limited by the signal-to-noise of the data. Hence we model galaxies as single metallicity populations and select the metallicity which yields the minimum χ^2. The details of the template fitting code will be presented in Tremonti et al. (in prep.).

After subtracting the best-fitting stellar population model of the continuum, we remove any remaining residuals (usually of order a few percent) with a sliding 200 pixel median, and fit the nebular emission lines. Since we are interested in recovering very weak nebular features, we adopt a special strategy: we fit all the emission lines with Gaussians simultaneously, requiring that all of the Balmer lines (Hδ, Hγ, Hβ, and Hα) have the same line width and velocity offset, and likewise for the forbidden lines ([OII] $\lambda\lambda 3726, 3729$, [OIII] $\lambda\lambda 4959, 5007$, [NII] $\lambda\lambda 6548, 6584$, [SII] $\lambda\lambda 6717, 6731$). We are careful to take into account the wavelength-dependent instrumental resolution of each fiber, which is measured for each set of observations by the SDSS spectroscopic pipeline from the arc lamp images. The virtue of constraining the line widths and velocity offsets is that it minimizes the number of free parameters and effectively allows the stronger lines to be used to help constrain the weaker ones. Extensive by-eye inspection suggests that our continuum and line fitting methods work well.

3 Parameters derived from Spectra

3.1 Stellar masses

References:
Kauffmann, G. et al., 2003, MNRAS, 341,33;
Kauffmann, G. et al., 2003, MNRAS, 341, 54

We developed a method to constrain the star formation histories, dust attenuation and stellar masses of galaxies. It is based on two stellar absorption line indices, the 4000 Å break strength and the Balmer absorption line index Hδ_A. Together, these indices allow us to constrain the mean stellar ages of galaxies and the fractional stellar mass formed in bursts over the past few Gyr. A comparison with broad band photometry then yields estimates of dust attenuation

and of stellar mass. The stellar mass catalogues include the 4000 Å break strength and Hδ_A measurements, stellar mass estimates, mass-to-light ratios, estimates of dust attenuation, and estimates of the fraction of the stellar mass formed in bursts in the past 2 Gyr.

3.2 Star formation rates

Reference:
Brinchmann, J. et al., 2004, MNRAS, in press (astro-ph/0311060)
Our methods for deriving star formation rates inside the fibre aperture make use of the methodology described in Charlot et al (2002) and emission line models described in Charlot & Longhetti (2001; CL01). The CL01 model is based on a combination of the Bruzual & Charlot (1993) and Ferland (1996, version C90.04) population synthesis and photoionization codes. In the model, the contributions to the nebular emission by HII regions and diffuse ionized gas are combined and described in terms of an effective (i.e. galaxy-averaged) metallicity, ionization parameter, dust attenuation at 5500 Å, and dust-to-metal ratio. The depletion of heavy elements onto dust grains and the absorption of ionizing photons by dust are included in a self-consistent way. We have developed a method to aperture correct our star formation rates using resolved imaging and we have shown that our method takes out essentially all aperture bias in the star formation rate (SFR) estimates, allowing an accurate estimate of the total SFRs in galaxies. Our catalogues also include estimates of the specific star formation rates of the DR2 galaxies (the star formation rate per unit stellar mass) both inside the fiber and for the galaxy as a whole.

3.3 Gas-phase metallicities

Reference:
Tremonti, C. et al., 2004, ApJ, in press (astro-ph/0405537)
Gas-phase metallicities have been measured using the approach outlined in Charlot et al (in prep.). The metallicity estimates are based on simultaneous fits of all the most prominent emission lines ([OII], Hβ, [OIII], [HeI], [OI], Hα, [NII], [SII]) using the CL01 models. In the paper referenced above, we compare our derived metallicities with estimates based on the ratio R_{23} = ([OII] + [OIII])/Hβ, and show that our estimates are similar to previous strong-line calibrations.

3.4 AGN catalogue

References:
Kauffmann, G. et al , 2003, MNRAS, 346, 1055;
Heckman, T.M. et al, 2004, ApJ, in press
AGN have been selected on the basis of their position on the BPT (Baldwin, Phillips & Terlevich 1981) diagram. We select AGN using the ratio [OIII]λ5007/Hβ versus the ratio [NII]/Hα for all galaxies where all four lines were detected with $S/N > 3$. In the studies referenced above, the luminosity of the [OIII] emission line was used as a tracer of the strength

of activity in the nucleus and these measurements are included in the catalogue along with the stellar velocity dispersions, which were used as an estimate of the black hole mass.

3.5 Emission line fluxes

In addition to our physical parameter estimates, we include a table of the measured emission line fluxes used in our work. These include [OII]λ3726,λ3729, Hβ, [OIII]λ5007, Hα, [NII]λ6584 and [SII]λ6717.

Acknowledgements

The data processing software developed for this project benefited from IDL routines written by Craig Markwardt and from the IDL Astronomy User's Library maintained by Wayne Landsman at Goddard Space Flight Center. C. A. T. thanks the Max Planck Institute for Astrophysics and the Johns Hopkins Center for Astrophysics for their generous financial support. She also acknowledges support from NASA grant NAG 58426 and NSF grant AST-0307386. J. B. and S. C. thank the Alexander von Humbolt Foundation, the Federal Ministry of Education and Research, and the Programme for Investment in the Future (ZIP) of the German Government for their support. J. B. would also like to acknowledge the receipt of an ESA post-doctoral fellowship.

Funding for the creation and distribution of the SDSS Archive has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium (ARC) for the Participating Institutions. The Participating Institutions are The University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, University of Pittsburgh, Princeton University, the United States Naval Observatory, and the University of Washington.

References

Abazaijian, K. et al, 2004, AJ, in press

Baldwin, J., Phillips, M., & Terlevich, R. 1981, PASP, 93, 5

Blanton, M.R., Lin, H., Lupton, R.H., Maley, F.M., Young, N., Zehavi, I., Loveday, J., 2003, AJ, 125, 2276

Brinchmann, J. et al., 2004, MNRAS, in press (astro-ph/0311060)

Bruzual, G., & Charlot, S. 2003, MNRAS, 344, 1000

Charlot, S., Longhetti, M., 2001, MNRAS, 323, 887

Charlot, S., Kauffmann, G., Longhetti, M., Tresse, L., White, S.D.M., Maddox, S.J., Fall, S.M., 2002, MNRAS, 330, 876

Ferland, G., 1996, Hazy, A Brief Introduction to Cloudy. Internal Report, University of Kentucky, USA

Fukugita, M., Ichikawa, T., Gunn, J.E., Doi, M., Shimasaku, K., Schneider, D.P. 1996, AJ, 111, 1748

Gunn, J. et al, 1998, ApJ, 116, 3040

Heckman, T.M. et al, 2004, ApJ, in press

Hogg, D., Finkbeiner, D., Schlegel, D., & Gunn, J. 2001, AJ, 122, 2129

Kauffmann, G. et al, 2003, MNRAS, 341, 33

Kauffmann, G. et al, 2003, MNRAS, 341, 54

Kauffmann, G. et al , 2003, MNRAS, 346, 1055

Pier, J., et al 2002 AJ, in press

Schlegel, D.J, Finkbeiner, D.P., Davis, M., 1998, ApJ, 500, 525

Smith, J.A. et al, 2002, AJ, 123, 2121

Stoughton, C. et al, 2002, AJ, 123, 485

Strauss, M. et al, 2002, AJ, 124, 1810

Tremonti, C. et al., 2004, ApJ, in press (astro-ph/0405537)

York, D.G. et al. 2000, AJ, 120, 1579